Management Effects on Clay Dispersibility of a Rhodic Paleudult in the Tennessee Valley Region, Alabama

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ABSTRACT

Conventional tillage coupled with monoculture cotton (*Gossypium hirsutum* L.) production has resulted in declining soil quality in the Tennessee Valley Region. However, conservation tillage systems that have been shown to increase soil quality are increasingly more common. Surface horizons in the region have appreciable silt and clay, which are mostly composed of quartz, kaolinite, hydroxy-interlayered vermiculite, and Fe oxides. Similar clay mineralogical suites have been shown to be dispersive under certain conditions, which can degrade soil physical properties. We evaluated the clay dispersibility of these soils cropped to cotton in: 1) a no-till system without a cover crop (NT), 2) a no-till system with a rye (*Secale cereale* L.) cover crop (NTC), 3) a no-till system with a rye cover crop and fall paratilling (NTCP), and 4) a conventional tillage system (CT). Soils consisted of fine, kaolinitic, thermic Rhodic Paleudults. Water dispersible clay (WDC), extractable Fe forms, and soil organic carbon (SOC) were evaluated for surface samples. Particle size distribution (PSD) and mineralogy of *in situ* soil, runoff sediment, and WDC were also evaluated. Increased clay amounts were recovered when samples had dithionite extractable Fe removed (Fe_d) compared to soil organic matter removal. The WDC quantities were positively correlated with SOC (%), which was higher under reduced *versus* conventional management and negatively correlated with Fe_d (%) and water stable aggregates (%). The aggregate of data suggests Fe oxides play a more vital role in clay aggregation than SOC in these soil systems. Particle size and mineralogy of runoff sediment collected under simulated rainfall was similar to *in situ* soil, suggesting models depicting erosion and nutrient runoff can be developed using *in situ* soil as a surrogate for sediment characterization.

KEYWORDS

Water dispersible clay, Ultisols, conservation tillage

INTRODUCTION

In recent years, reduced tillage systems have become common in the Tennessee Valley region of Alabama. These soils are mostly Ultisols with surface horizons possessing appreciable silt and clay particles. Quartz dominates the sand and coarse silt fractions, and kaolinite and hydroxy-interlayered vermiculite are found in the fine silt and clay fractions. Relatively high quantities of Fe oxides are found in both surface and subsurface horizons.

Similar soil mineralogical systems have been shown to possess appreciable quantities of water dispersible clay (WDC) under certain conditions (Miller and Baharuddin, 1986; Miller and Radcliffe, 1992; Chiang *et al*., 1994). Water dispersible clay has been correlated with erodibility (Bajracharya *et al*., 1992) and relatively high quantities of WDC results in soil crusting (Chiang *et al*., 1994), which decreases infiltration (Zhang and Miller, 1996). Studies have established WDC quantities are correlated with total clay content, soil organic matter content (SOM), dithionite extractable Fe and Al content, exchangeable cations, pH, and ionic strength (Goldberg *et al*., 1990; Miller *et al*., 1990; Brubaker *et al*., 1992; Heil and Sposito, 1993).

Due to the importance of water dispersible particles to soil properties, this study was undertaken to: 1) develop an understanding of the interactions of management systems on the dispersion characteristics of surface soils in the Tennessee Valley Region, and 2) characterize sediment and dispersed particles from these soils.

MATERIALS AND METHODS

Our research site was located at the Belle Mina Experiment Station in the Tennessee Valley Region of Alabama. Soils possessed fine-textured surface horizons, and were classified as fine, kaolinitic, thermic Rhodic Paleudults (Table 1). Soils are moderately to severely eroded due to historical conventional tillage management during inten-

sive cotton (*Gossypium hirsutum* L.) monocropping. However, since 1996, conservation tillage management systems using cover crops are now predominant in the region. The study site was part of a long-term experiment (1995 to present) evaluating conservation *versus* conventional tillage management systems cropped to cotton in a RCB design with four replications (Schwab *et al*., 2002). We selected four treatments (plots are 8 m wide x 15 m long) consisting of no-till without a cover crop (NT), no-till with a rye (*Secale cereale* L.) cover crop (NTC), no-till with a rye cover crop and fall paratilling (NTCP), and a conventional tillage system (CT) that consisted of disking and chisel plowing in the fall, followed by disking and leveling in the spring.

For deep pedon characterization, soils were sampled by horizon according to National Cooperative Soil Survey Standards. Particle size determination, cation exchange capacity, exchangeable cations, extractable Al, base saturation, and pH were analyzed according to standard techniques (Soil Survey Investigations Staff, 1996).

Soils were composite ($\approx$ -20) sampled at the 0-1 cm depth in the four replications of the selected treatments. Soil organic carbon (SOC) was measured using dry combustion (Yeomans and Bremner, 1991). Organically bound Fe was extracted with sodium pyrophosphate (Fe_p), non-crystalline (poorly crystalline and organically bound) Fe was extracted with acid ammonium oxalate (Fe_o), and total Fe oxides and organically-bound Fe were extracted with dithionite-citrate-bicarbonate (Fe_d) (Jackson *et al*., 1986). Particle size was determined with: 1) SOM removed (using H_2O_2), 2) Fe_d removed, and 3) both SOM and Fe_d removed (Kilmer and Alexander, 1949). The WDC was measured using the method of Miller and Miller (1987). The WDC was measured using both distilled H_2O (H_2O_d) and well water used during rainfall simulation experiments (H_2O_{TV})

[pH=7.41, EC= 0.17 dS m^{-1}, total electrolyte concentration (TEC)=2 mol$_c$ m^{-3}, Ca=33.2 ppm, Na=1.7 ppm].

Water stable aggregates (WSA) (0-3 cm) were determined for composited (5) samples for the first and third replication using the method of Kemper and Rosenau (1986). The first and third replications were chosen to coincide with rainfall simulation experiments (first replication in the fall, third replication used in spring, see Truman *et al*., in review).

Rainfall simulation experiments were conducted during November, 1999 on duplicate 1-m^2 plots placed within the first replication (Truman *et al*., in review). Briefly, rainfall was applied to duplicate plots within each treatment at a target intensity of 50 mm h^{-1} using an oscillating nozzle rainfall simulator. Rain was applied for 1 h, paused for 1 h, and then resumed for 1 additional h. Runoff sediment was collected at an outlet placed on the corner of each plot.

Runoff sediment, WDC (from first replication), and *in situ* soil samples (from first replication) were fractionated into fine (0-0.2μm) and coarse clay (0.2-2 μm) after organic matter removal using standard techniques (Jackson, 1975). Oriented clay fractions were examined by XRD using these treatments: Mg-saturation / ethylene glycol solvation @ 25C, Mg-saturation @ 25 C, K-saturation @ 25C, 300C, and 550C. Magnesium-saturated clay fractions were analyzed using thermogravimetric analyses (TGA). Hydroxy-interlayered vermiculite (HIV) and quartz (Qtz) quantities were estimated using the techniques of Karathanasis and Hajek (1982).

RESULTS AND DISCUSSION

The 0-1 cm depth in these soils possessed appreciable clay (Table 2). Overall, for particle-size measurements with SOM removed (standard procedure), the CT plots possessed slightly higher clay than all of the NT treatments,

Table 1. Soil characterization data for the Tennessee Valley site (fine, kaolinitic, thermic Rhodic Paleudult). Values for Ca, Mg, K, and Na are NH_4OAc extractable bases, values for Al are the KCl extractable quantity, ECEC is the effective cation exchange capacity, CEC is the cation exchange capacity, pH is the pH in 1:2 soil:water, and BS is the base saturation.

Horizon	Depth	Sand	Silt	Clay	Ca	Mg	K	Na	Al	ECEC	CEC	pH	BS
	-- cm --	--------- % ----------			-------------------- cmol kg^{-1} --------------------								- % -
Ap1	0 –19	15.3	54.2	30.5	3.36	0.42	0.63	0.01	0.07	4.49	8.91	5.10	49.6
Ap2	19-30	12.7	51.8	35.5	4.14	0.49	0.59	0.01	0.06	5.29	10.01	5.52	52.2
Bt1	30-46	10.0	39.4	50.6	3.36	0.44	0.41	0.02	0.85	5.08	11.87	4.62	35.6
Bt2	46-110	10.0	36.3	53.7	2.20	0.45	0.25	0.01	1.15	4.06	10.49	4.44	27.7
Bt3	110-150	9.1	27.9	63.0	1.38	0.52	0.26	0.01	2.21	4.39	10.90	4.10	19.9

reflecting the more thorough mixing of surface and subsurface soils and possibly a slightly higher degree of erosion for CT treatments. In the southeastern region, eroded soils typically have finer-textured surface horizons due to the exposure of argillic horizons and the mixing of these clay-rich subsurface horizons with surface horizons through tillage (Olson *et al.*, 1994).

Many studies have shown the role SOM plays in clay aggregation, which is partly attributed to clay-organic interactions facilitated through cation bridging (Oades, 1989). However, for these soils, the amount of clay recovered increased when Fe_d was removed compared to SOM removal (Table 2). In fact, recovered clay quantities were similar with Fe_d removed compared to having both Fe_d and SOM removed (Table 2). These data suggest Fe_d plays a more substantial role in aggregating clay minerals in these soils than SOM. The Fe_d is composed of "free" Fe oxides, which consist of crystalline (hematite, goethite), poorly crystalline (ferrihydrite and other forms), and organic Fe forms. The high proportion of Fe_d compared to Fe_o (poorly crystalline) and Fe_p (organic forms) suggests much of the free Fe is in crystalline oxide form (Table 2). At the resident pH of these soil systems (5 to 6), Fe oxides possess an appreciable (+) charge (ZPC from 6.5-7.5), thus promoting the bridging of (-) charged phyllosilicate surfaces (e.g., kaolinite has a ZPC from 3.5-5). Although in many surface soils SOM plays a large role in clay aggregation, our data suggests in these soil systems (>2.5% Fe_d on a whole-soil basis) Fe oxide minerals play a more substantial role.

Overall, an average of 14% (H_2O_{TV}) to 18% (H_2O_d) of the clay fraction was water-dispersible (Table 2). Brubaker *et al.* (1992) analyzed soils from eight orders and found an average of 34% of the clay fraction was water-dispersible. Our soils have relatively less WDC overall, likely due to the high quantities of Fe oxides in these soil systems. The slightly greater amount of WDC using H_2O_d is likely due to a combination of lower total electrolyte concentration (TEC) for this treatment, and the relatively higher Ca in the H_2O_{TV} treatment causing a slight decrease in the double layer and slightly reduced dispersion. It has been suggested in highly weathered systems with low TEC, such as mimicked with the H_2O_d treatment, repulsive forces between clays result in increased dispersion (Kaplan *et al.*, 1996).

No relationship existed with regard to H_2O_d dispersible clay quantities and SOC or Fe_d (Fig. 1a and b). However, the H_2O_{TV} dispersible clay quantities increased with increasing SOC (r^2=0.65) and decreased with increasing Fe_d (r^2=0.35) (Fig. 1c and d). Studies

have indicated in some systems, SOC may enhance dispersion by decreasing Ca activities while increasing negative charges on clay colloids (Oades, 1984). For these soils, increasing Fe oxide quantities resulted in a general decrease in WDC. We also found WDC was exponentially related to percent water stable aggregates (WSA), suggesting WDC should be included in soil quality data sets (Figure 2).

The runoff sediment was similar in texture to *in situ* soil (Table 3). Similarities in texture between sediment and soil is consistent with results obtained by Meyer *et al.* (1992) and Shaw *et al.* (in review) for other Southeastern soils.

Table 2. Average (standard deviation of the mean) soil physical and chemical characteristics (r = 4) at the 0-1 cm depth.

Treatment[†]	Clay without			Iron				WDC[¶]	
	OM	OM, Fe	Fe	Fe_d [‡]	Fe_o	Fe_p	SOC[§]	TV	DI
	------------- % -------------								
NT	21.5(1.8)	29.3(2.4)	30.2(2.0)	2.72(0.23)	0.36(0.03)	0.02(0.01)	1.41(0.12)	20.1(6.4)	18.1(1.7)
NTC	22.4(4.2)	29.6(2.6)	31.9(3.1)	2.63(0.20)	0.32(0.05)	0.02(0.01)	1.65(0.46)	23.1(7.3)	15.9(2.8)
NTCP	27.9(2.9)	33.8(2.7)	35.3(3.1)	2.93(0.22)	0.36(0.10)	0.01(0.0)	1.05(0.19)	11.5(6.9)	22.7(2.8)
CT	28.1(3.5)	34.0(3.0)	35.2(3.7)	2.83(0.18)	0.38(0.06)	0.01(0.0)	0.81(0.07)	2.8(2.3)	18.3(2.8)

[†]NT=no tillage, NTC= no tillage with cover crop, NTCP= no tillage with cover crop and fall paratilling, CT=conventional tillage.
[‡]Fe_d, Fe_o, and Fe_p are sodium dithionite, ammonium oxalate, and sodium pyrophosphate extractable Fe, respectively.
[§]SOC= soil organic carbon.
[¶]WDC= water dispersible clay as a percentage of total clay; TV= simulation water, DI= deionized water.
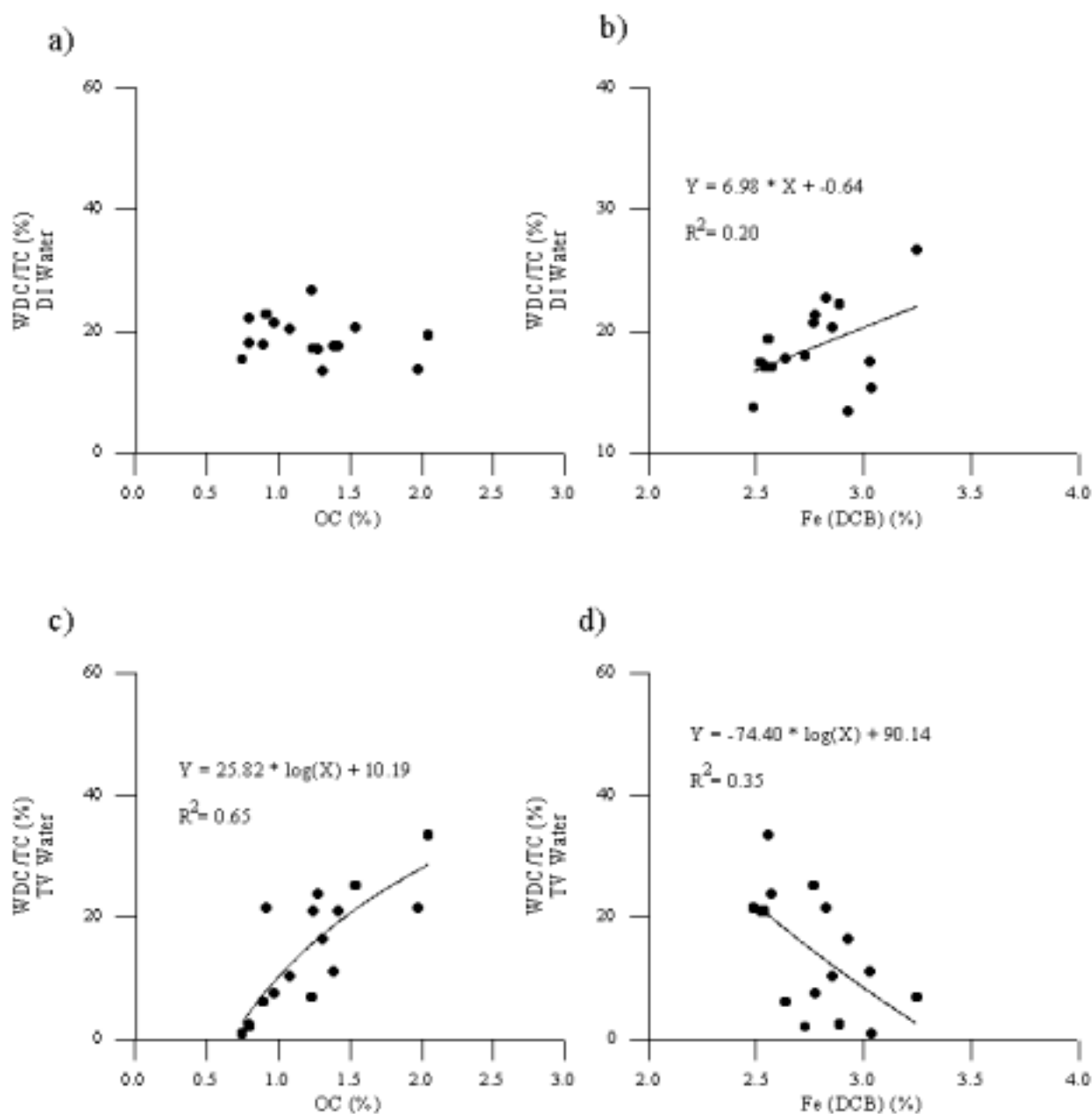
Fig. 1. Relationship between a) water dispersible clay (WDC)/total clay (TC) and SOC (%) for DI water, b) WDC/TC and DCB Fe (%) for DI water, c) WDC/TC and OC (%) for TV water, and d) WDC/TC and DCB Fe (%) for TV water. TV water composition described in methods.

Analyses of the clay mineralogy of the *in situ* soil, runoff sediment, and WDC suggest little enrichment of specific clay minerals in transported *versus in situ* soil. Similar quantities of kaolinite, hydroxy-interlayered vermiculite (HIV), quartz, and Fe_d were observed between the soil, sediment, and WDC (Table 4). These data suggest models depicting off-site nutrient movement do not need to incorporate enrichment ratios for specific particle size separates and minerals, i.e., characterization of *in situ* texture and mineralogy adequately reflect sediment size characteristics and mineralogical composition.

CONCLUSIONS

Increasing amounts of dispersible clay has been shown to decrease infiltration as well as generally degrade soil physical properties. It is widely accepted that in many soil systems, increases in SOM resulting from conservation tillage systems generally result in increased infiltration rates. Results from a companion study (Truman *et al.*, in review) suggested minimal differences in infiltration between the CT, NT, and NTC treatments of this experiment, which may be due to the clay dispersion phenomena shown in this study. Infiltration rates were greatly increased in the no surface tillage systems with non-inversion deep tillage

Table 3. P article-size of soil and sediment collected during a rainfall simulation experiment on first replication. Numbers in parentheses are standard deviations of means.

| Treatment[†]	Soil			Sediment		
	Sand	Silt	Clay	Sand	Silt	Clay
	-- % ---					
NT	6.8	74.3	19.0	4.5(0.8)	71.8(0.3)	23.7(1.1)
NTC	8.0	72.4	19.6	4.2(0.6)	65.2(1.2)	30.5(1.8)
NTCP	11.6	58.8	29.6	8.0(0.2)	61.9(1.5)	30.1(1.3)
CT	10.5	56.2	33.3	8.4(0.4)	57.1(2.9)	34.5(2.4)

†NT = no tillage, NTC = no tillage with cover crop, NTCP = no tillage with cover crop and fall paratilling, CT = conventional tillage.

Table 4. Comparison of mineralogical composition of clay (< 2 μm) fraction between *in situ* soil, runoff sediment, and WDC. Mineral quantities averaged over all treatments for first replication. Recovered mineral quantities normalized to 100%. Numbers in parentheses are standard deviations of mean.

	0 - 0.2 μm				0.2 - 2 μm			
	Kao	HIV	Qtz	Fe$_d$	Kao	HIV	Qtz	Fe$_d$
	-- % --							
Soil	49.1(3.5)	42.2(3.1)	0.0(0.0)	8.7(0.4)	37.8(2.6)	43.0(3.9)	13.0(6.2)	6.2(0.6)
Sediment	44.5(1.9)	45.0(2.0)	0.0(0.0)	10.5(1.0)	34.7(1.6)	44.6(2.5)	12.3(1.0)	8.4(1.5)
WDC	44.9(1.8)	46.1(2.5)	0.0(0.0)	9.0(1.0)	31.9(4.4)	45.3(1.2)	15.6(3.9)	7.2(0.7)

[†] Kao=kaolinite, HIV= hydroxy-interlayered vermiculite, Qtz=quartz, Fe$_d$ = dithionite extractable Fe.

(NTCP), which suggests the mechanical disruption induced by deep tillage overwhelms surface soil WDC effects on infiltration. Corollary relationships observed in a study of Southeastern Coastal Plain soils (Shaw *et al.*, in review) between SOM, water stable aggregates, and infiltration were not evident in these soils. Future work should evaluate the effects of liming and other amendment applications for stabilizing organic matter and refining reduced tillage systems in this region.
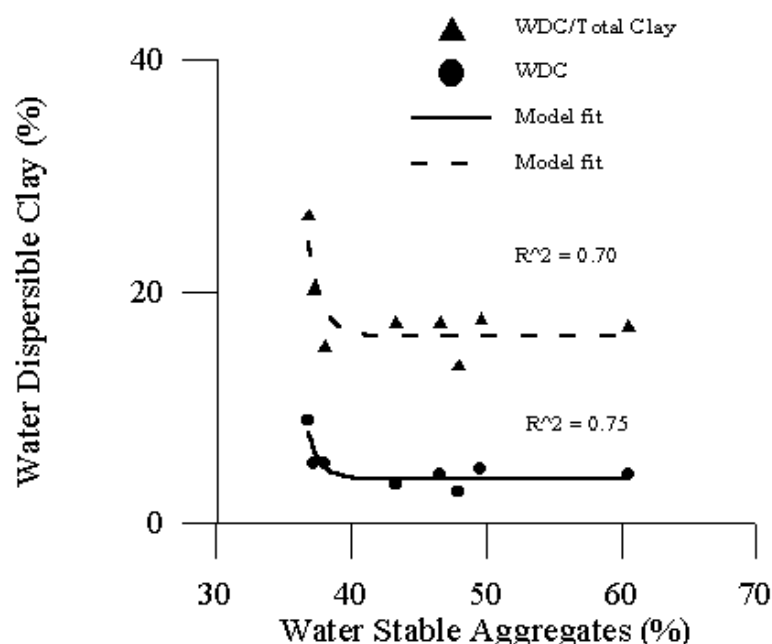
Fig. 2. The relationship between water stable aggregates and water dispersible clay for the first and third replications.

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